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AD 831971

TECHNICAL REPORT

68-37-CM

CAMOUFLAGE OF THE INDIVIDUAL SOLDIER AT NIGHT

by

Alvin O. Ramsley

March 1968

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

U.S. ARMY MATERIEL COMMAND

Clothing and Organic Materials Laboratory

C&OM-41

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TECHNICAL REPORT

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Project Reference:
1TO-24401-A329

Series: C&OM-41

Clothing and Organic Materials Laboratory
U.S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

FOREWORD

With the advent of more sensitive and sophisticated surveillance devices for use at night, it is necessary to re-examine the requirements for personal, night camouflage. This report compares the typical characteristics of image intensifier detection systems with those of the more familiar sniperscope. An analysis of the properties of illumination, detector, and terrain suggests that ideal camouflage against the image intensifier will require near infrared reflectances that are somewhat higher than those established for camouflage against the sniperscope.

The work covered in this report was performed in the Textile Dyeing Division, Clothing and Organic Materials Laboratory, under Project 1TO-24401-A329, Organic Materials Research for Army Materiel, under the general supervision of Mr. Frank J. Rizzo.

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ABSTRACT

Until the appearance of the sniperscope, a soldier in the field was severely restricted in conducting nighttime surveillance. Since that time, other devices known as image intensifiers have appeared. Although similar in some respects, use of the image intensifier differs from that of the sniperscope in certain basic respects, particularly in that it can function with only the illumination of the night sky.

The object of this study is to determine whether new criteria for personal camouflage exist as the result of the emergence of the image intensifier. Topics considered include: spectral energy distribution of radiation from the night sky, spectral sensitivity functions of typical detectors, reflectance characteristics of the terrain, and the geometric conditions of viewing a scene with the image intensifier. The analysis leads to the conclusion that ideal camouflage against the image intensifier requires reflectance values somewhat higher than those adopted with respect to the sniperscope.

CAMOUFLAGE OF THE INDIVIDUAL SOLDIER AT NIGHT

1. Introduction

Although both camouflage and surveillance are ancient arts, it is only recently that an observer's capability has been augmented by devices that are the products of electro-optical technology. Until the appearance of the infrared sniperscope, a soldier in the field was severely restricted in nighttime surveillance. Since that time, other promising devices have appeared, the prototypes of which are variously referred to as image intensifiers or light amplifiers.[1-5]

Image intensifiers resemble the more familiar sniperscope in some important respects. In both cases, the information used by the observer is presented on a screen as the image of the scene being observed. Moreover, both instruments may be mounted on small arms and fitted with reticles as sighting devices, in a manner similar to that employed with visual telescopes.

The image intensifier, however, differs from the sniperscope in certain basic respects. The sniperscope is an active device that requires an associated source to illuminate the object being observed. To preserve the security of the user, this source provides only near infrared radiation. On the other hand, the image intensifier needs only the illumination of the night sky to function and may therefore respond to both the visible and near infrared portions of the spectrum.

2. Scope of Study

This report considers three aspects of the general problem with a unifying emphasis on the impact of image-intensifier night-viewing devices on the criteria for camouflage of the individual combat soldier. The problem may be phrased succinctly by asking three simple questions:

a. Is the nature of the illumination of the night sky sufficiently different from daylight to establish new camouflage requirements?

b. Do image intensifiers possess characteristics that are sufficiently different from visual or sniperscope responses to impose unique material requirements for personal camouflage?

c. Do fabric surfaces reflect light of the night sky differently from that of daylight so as to establish unique requirements?

3. Analysis of Problem

The intensity of an element in the image formed on the screen of the image intensifier may be expressed as:

$$I = A \int_{\lambda_1}^{\lambda_2} E_\lambda S_\lambda R_\lambda \, d\lambda \qquad (1)$$

where E_λ is a function of the spectral energy distribution of illumination,

S_λ is the spectral sensitivity of the photosensitive detector,

R_λ is spectral reflectance of the portion of the object that corresponds to the element of the image being considered,

A is a constant that includes the amplification factor of the device,

λ is wavelength.

Whether this element can be distinguished from the background against which it is viewed depends on the value of I for the element in comparison with that for nearby portions of the background. The difference in values is contrast, C, expressed as:

$$C = \frac{I - I_B}{I_B} \qquad (2)$$

where I_B is the intensity of the background.

If the absolute value of C is above a limiting value, the target element can be distinguished from the neighboring background. For good viewing conditions, the visual threshold contrast ratio is about 0.02. This minimum value increases as viewing conditions depart from the ideal, as influenced by level of illumination, range of observation, size of target, condition of the atmosphere, and the visual ability of the observer. These topics have been the subject of many studies[6] dealing with visual observation; comparable information is not available for observation with an image intensifier.

a. Illumination from the Night Sky

Although the source is the relatively constant sun, natural illumination by day varies considerably because of atmospheric conditions and other

factors. In 1931, the C.I.E. defined two sources, "B" and "C", that are internationally-agreed-upon average spectral distributions of direct sunlight and diffuse skylight (6500°K), respectively. Actual distributions of both types of light may depart considerably from the standard distributions, depending on the degree of haze, cloud cover, and time of day. Despite the variations, the standard distributions for daytime natural illumination have been found practical in both colorimetry and illuminating engineering.

Although the specification of daytime illumination is difficult, that for the natural light at night poses an even more formidable task. The spectral distribution of the energy of the night sky with the moon shining is very different from that on moonless nights. Moreover, the contribution of moonlight to the total depends on the phase of the moon. Since moonlight is simply light from the sun reflected by a nearly neutral lunar surface, much of its energy is in the visible spectrum, as modified by the intervening atmosphere. Under these conditions, direct visual observation is quite effective, especially when aided by simple binoculars.

Even on moonless nights the problem of adopting a standard spectral distribution is not simple. The situation is further complicated by the intermittent occurrences of variable auroràe, especially at the higher latitudes. Since the image intensifier is potentially most useful when direct observation is inadequate, this report does not consider those situations where illumination of the night sky is augmented by moonlight, aurorae, back-scatter from urban centers or other artificial sources.

Both the total intensity and spectral distribution of the moonless night sky vary systematically with the time of night, season of the year, latitude, and sporadically with extraterrestrial influences.[9] Furthermore, the intensity of illumination varies from one area of the night sky to another and atmospheric factors exert their unpredictable influences. Thus, it is obvious that one should not expect to find a "standard curve" for the spectral distribution of the night.

Despite the wide range of results that one might expect, Figure 1 shows two curves that have been reported for the spectral distribution of radiation from the moonless night sky.[7,8] (These data also apparently neglect consideration of aurorae). That the intensities depicted by the two curves differ by a factor of four or more should be attributed more to the variability discussed above than to experimental technique. The one characteristic of the two curves that should be pointed out is the considerable similarity that exists. More detailed structure in the spectra throughout the photographic range for both the night glow and aurorae have been reported by Chamberlain and Meinel.[9] Pavlova and others[10] have calculated the proportions of the energy in various regions of the spectrum of the night sky. Table I is an adaptation of their data published elsewhere.[11] These data are quite consistent with those of Figure 1.

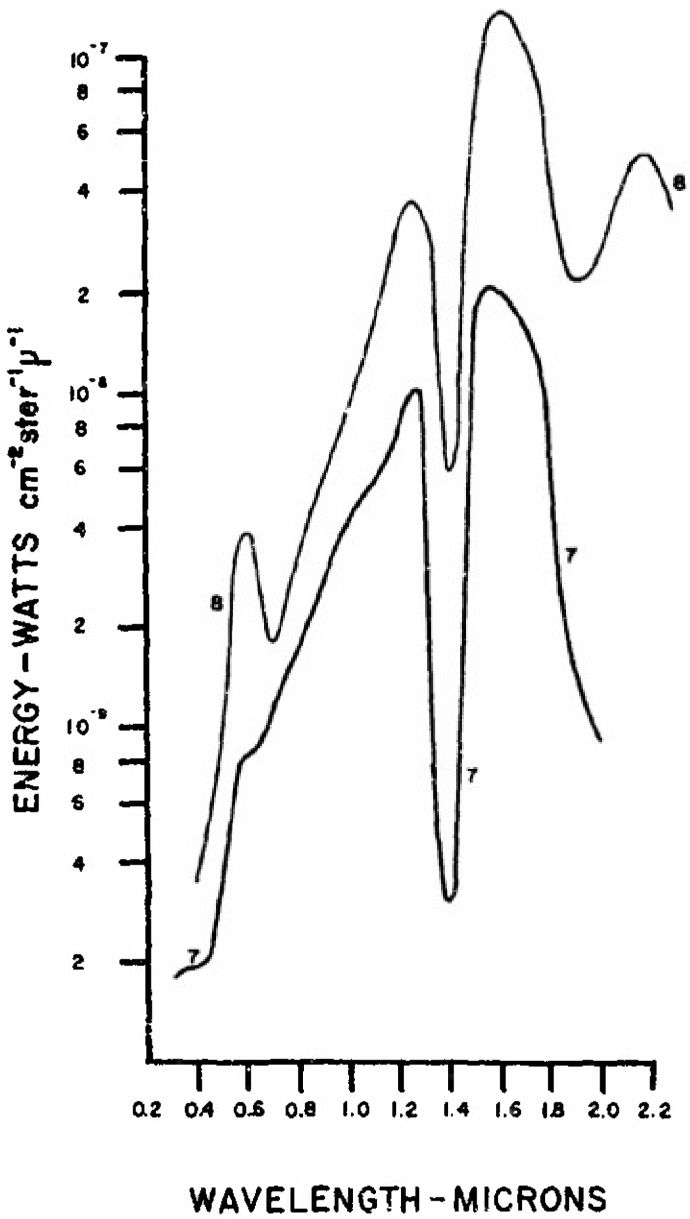

Figure 1. Spectral Energy Distribution of the Clear, Moonless Night Sky Reported by Two Sources.(7,8)

Chapman[12] has reported that the intensity rises sharply by a factor of 10 or more at wavelengths longer than those shown in Figure 1.

TABLE I

RELATIVE RADIATION IN PORTIONS OF THE SPECTRUM OF THE NIGHT SKY

SPECTRAL REGION	TOTAL ENERGY ergs x $10^4 cm^{-2} sec^{-1} ster^{-1}$
320 to 360 nm	1
540 to 570 nm	1
750 to 900 nm	30
900 to 1075 nm	100

To summarize, under the conditions in which an image intensifier can clearly demonstrate its superiority, the illumination from the night sky may be considered to be diffuse and very weak in the visible spectrum but increasingly strong as the wavelength increases.

b. Response of Image Intensifiers

Although a variety of photo-sensitive surfaces may be used in image intensifiers and intensive research on such detectors is in progress,[2] the open literature suggests that detectors with S-1, S-4 and S-10 surfaces have frequently been employed in development of image intensifiers. Figure 2 depicts the nominal spectral response functions for these surfaces. For comparison, the scotopic visual sensitivity function for the dark-adapted eye is also shown in Figure 2.

A comparison of Figures 1 and 2 makes it obvious that future research will emphasize the extension of sensitivity to wavelengths in the 1 to 2-micron region. For the purpose of this report, only the S-1 surface will be considered.

Figure 3 depicts the product of the S-1 sensitivity function and the spectral energy distribution of the night sky reported by Stark and Manley,[7] plotted as a function of wavelength. From this curve, it may be seen that only about 1/8 of the response lies in the visible region of the spectrum under unencumbered conditions. Under field conditions, where some of the illumination is due to reflected radiation, the visible portion of Figure 3 becomes even less significant, because the reflectivity of most terrain components is comparatively low in the visible region of the spectrum. Moreover, Figure 1 shows that as research extends the range of sensitivity to longer wavelengths, the visible region may virtually be neglected, a conclusion which has considerable practical consequences.

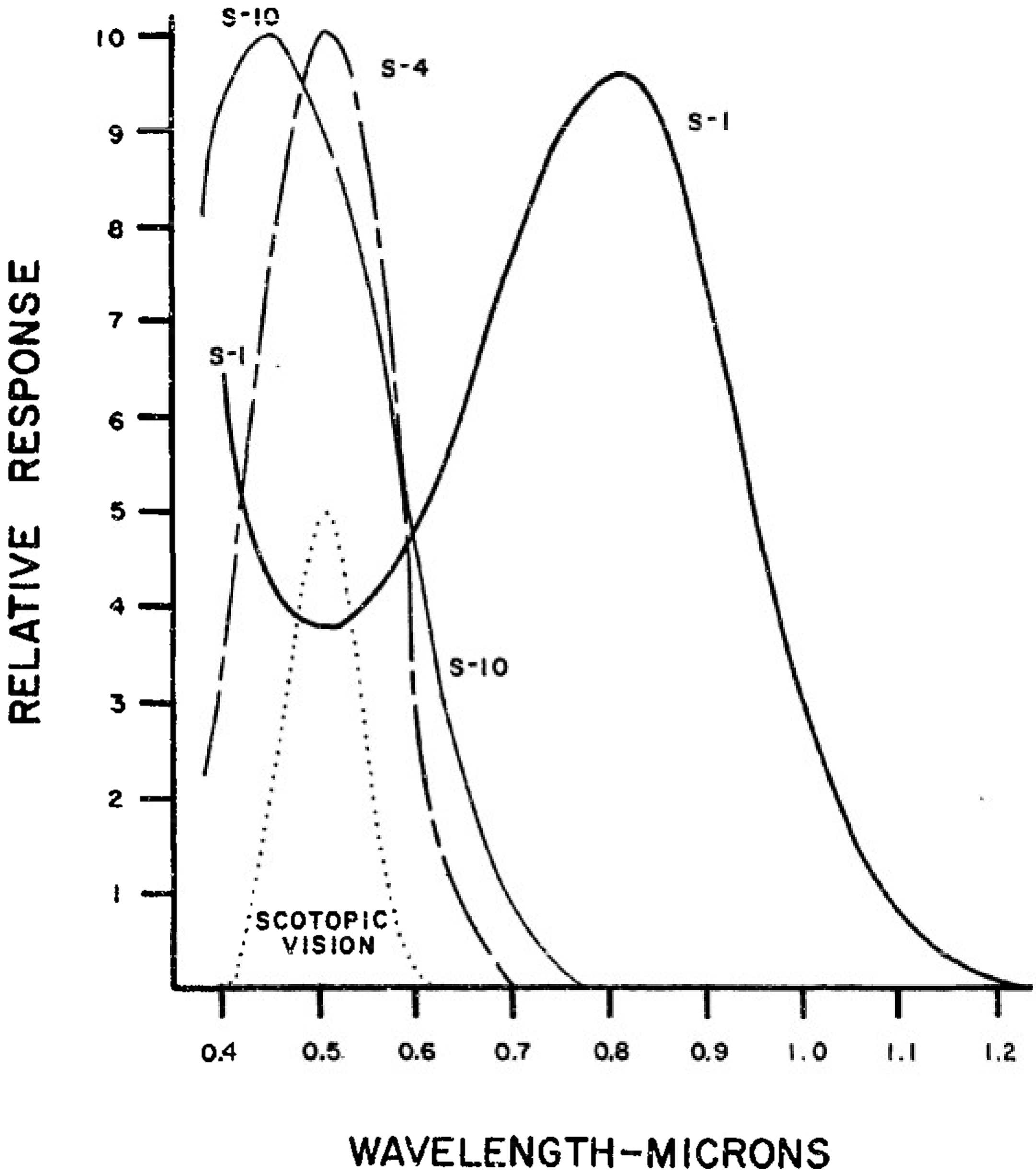

Figure 2. Spectral Sensitivity Function for Scotopic Vision and for Certain Detectors.

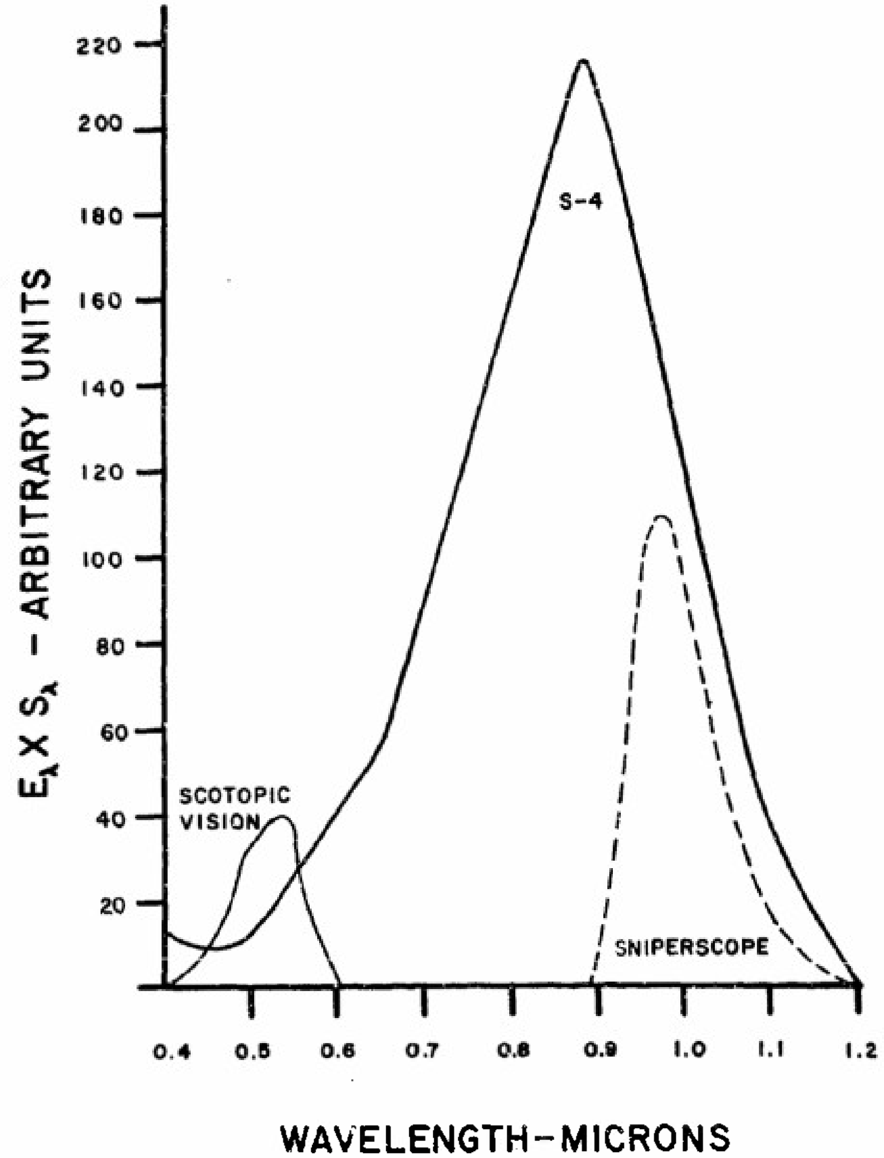

Figure 3. Product of Spectral Sensitivity and Energy Distributions for an Image Intensifier with an S-4 Detector and Scotopic Vision on a Clear, Moonless Night and for the Sniperscope with Its Usual Infrared Source.

c. Reflectance of Textiles

For any given observation, both E_λ and S_λ remain the same, and thus the value of their product is constant. It is then possible to simplify Equation 1 to

$$I = AT\int_{\lambda_1}^{\lambda_2} D_\lambda \quad R_\lambda \quad d\lambda \qquad (3)$$

where T is a weighting factor for the overall intensity of the radiation and

D_λ is the product E_λ S_λ

Thus, the intensities of an element and its associated background are largely determined by their respective reflectances.

Reflectance is defined as the ratio Is/Io, where Is is the intensity of light reflected from a test surface and Io is that of light reflected under the same conditions by a perfectly diffuse non-absorbing, opaque standard surface such as MgO. Since radiation is neither transmitted nor absorbed by the standard surface, Io must be proportional to the intensity of the incident radiation. A basic presumption is that this ratio Is/Io is independent of the incident intensity. This presumption however, does not appear to have been tested explicitly.

To test this presumption, Tables II and III summarize reflectance measurements of two fabric samples made between 400 and 650 nm with a Beckman DU Spectrophotometer and 1P28 Photomultiplier Tube. Because of drastically reduced sensitivity at longer wavelengths, the measurements were restricted to the range indicated. Measurements were made relative to magnesium carbonate at levels of intensity in the illuminating beam that varied over six orders of magnitude, controlled by inserting neutral filters* at the exit slit into the optical path. The filters had optical densities of 1.0, 2.0 and 3.0. The column of data headed by D=0 was obviously obtained without use of any filter, whereas it was necessary to use combinations of the three filters to reduce intensities by orders of magnitude above 3, as shown in the last three columns of Tables II and III.

The column headings "D" show the density of filters used. Slit width for the data of Table II was maintained constant at 2 mm; for the data of Table III, slit widths were as indicated.

*Note: Filters were obtained from Oriel Optics Ind., Stamford, Conn. Ser. Nos. 113, 127, 139

TABLE II

REFLECTANCE OF OLIVE GREEN SHADE* AT SIX LEVELS
OF ILLUMINATION AS A FUNCTION OF WAVELENGTH

(nm)	D=0	D=2	D=3	D=4	D=5	D=6
650	5.9	6.0	5.9	6.0	6.2	6.2
625	6.6	6.5	6.6	6.5	6.8	6.6
600	7.3	7.2	7.3	7.2	7.4	7.1
575	7.9	7.8	7.9	7.8	7.8	7.7
550	7.7	7.7	7.6	7.7	7.8	7.9
525	6.5	6.5	6.5	6.5	6.8	6.7
500	5.8	5.8	5.7	5.8	5.8	6.1
475	5.0	5.0	5.1	5.2	5.3	5.0
450	4.3	4.3	4.4	4.5	4.6	5.0
425	4.0	4.1	4.0	4.2	---	4.0
400	3.9	3.9	3.9	4.0	---	---

*Note: Fabric used was cloth, cotton, sateen, 9 ounces per square yard, Olive Green 107

TABLE III

REFLECTANCE OF KHAKI SHADE* AT SIX LEVELS OF ILLUMINATION AS A FUNCTION OF WAVELENGTH

	Slit width = 1.00 mm				1.85 mm		1.50 mm
(nm)	D=0	D=2	D=3	D=4	D=4	D=5	D=6
650	33.9	33.1	32.9	33.1	32.4	32.7	32.7
625	29.8	28.8	28.9	28.9	28.9	29.1	28.3
600	26.9	26.6	26.5	26.6	26.8	26.9	27.1
575	26.3	25.6	25.6	25.6	25.7	25.8	26.0
550	25.3	24.8	24.9	25.0	24.9	24.9	24.7
525	23.9	22.9	22.9	23.0	23.2	23.2	23.8
500	20.1	19.4	19.5	19.6	20.2	20.2	20.5
475	16.8	16.4	16.5	16.6	17.1	16.9	16.6
450	15.8	15.3	15.5	15.5	15.8	15.6	15.8
425	16.8	16.2	16.2	16.2	16.2	---	15.2
400	17.2	17.0	17.0	17.0	17.2	----	----

*Note: Fabric used was cloth, cotton, sateen, 8.2 ounces per square yard, Khaki 1.

From the data of Tables II and III, it seems clear that reflectance at any given wavelength is independent of intensity of illumination at the levels considered in this study. There is no reason to suppose that a different result would be found at wavelengths above 650 nm.

4. Discussion and Conclusions

From the foregoing analysis, it is evident that the development of the image intensifier requires a reconsideration of the requirements for personal camouflage. It has been shown that the nature of the illumination of the

night sky predominates in the infrared rather than the visible spectrum (Figure 1). This is opposite of the sun daylight.

Figure 3 demonstrates that camouflage against image intensifiers, even with available detectors, must emphasize the near infrared region of the spectrum. Specifically, it shows that an image intensifier equipped with an S-1 detector has a peak sensitivity at a wavelength somewhat lower than that for the infrared sniperscope system. It is expected that this difference will be narrowed as research on detectors proceeds.

In order to estimate the reflectance requirements for ideal camouflage against the image intensifier, the reflectance characteristics of typical terrain components must also be known. Figures 4 through 8 present average reflectance curves from 0.4 to 2.2 microns that have been published in the literature.(13) Since the original data were obtained by several investigators under a variety of conditions, these curves should only be considered representative of the types of materials that are illustrated.

Figure 4 shows a published curve for the green beet leaf that may be taken as representative of leafy vegetables in general. It also depicts the reflectance curve of both fresh and dry sorghum grass. Curves for alfalfa, wheat, corn, orchard grass, and barley were similar.(13) The curves for various types of bark varied widely, depending on their source. Figure 5 shows a range within which reflectance curves for bark fall.

Typical reflectance curves for leaves of deciduous trees are depicted in Figure 6. Once again, because of variations reported, curves for dry leaves show a range of values.

Figures 7 and 8 show reflectance curves for loam, clay, sand, rocks, and certain building materials. Thse must only be considered as representative of the types of materials illustrated.

Examination of these figures shows that except for certain inorganic materials, the reflectance of most terrain components is high in the spectral region in which the sniperscope normally operates. Values above 50 percent are commonplace. Nevertheless, field studies have demonstrated that the reflectance that affords the best camouflage against detection by the sniperscope is much lower than components of the terrain against which an object is viewed. It is apparent, therefore, that a simple matching of reflectances is not the essential criterion.

The significant difference between the image intensifier and the sniperscope is not one of spectral sensitivity but that of the geometry of illumination of the object being viewed. Perhaps an examination of

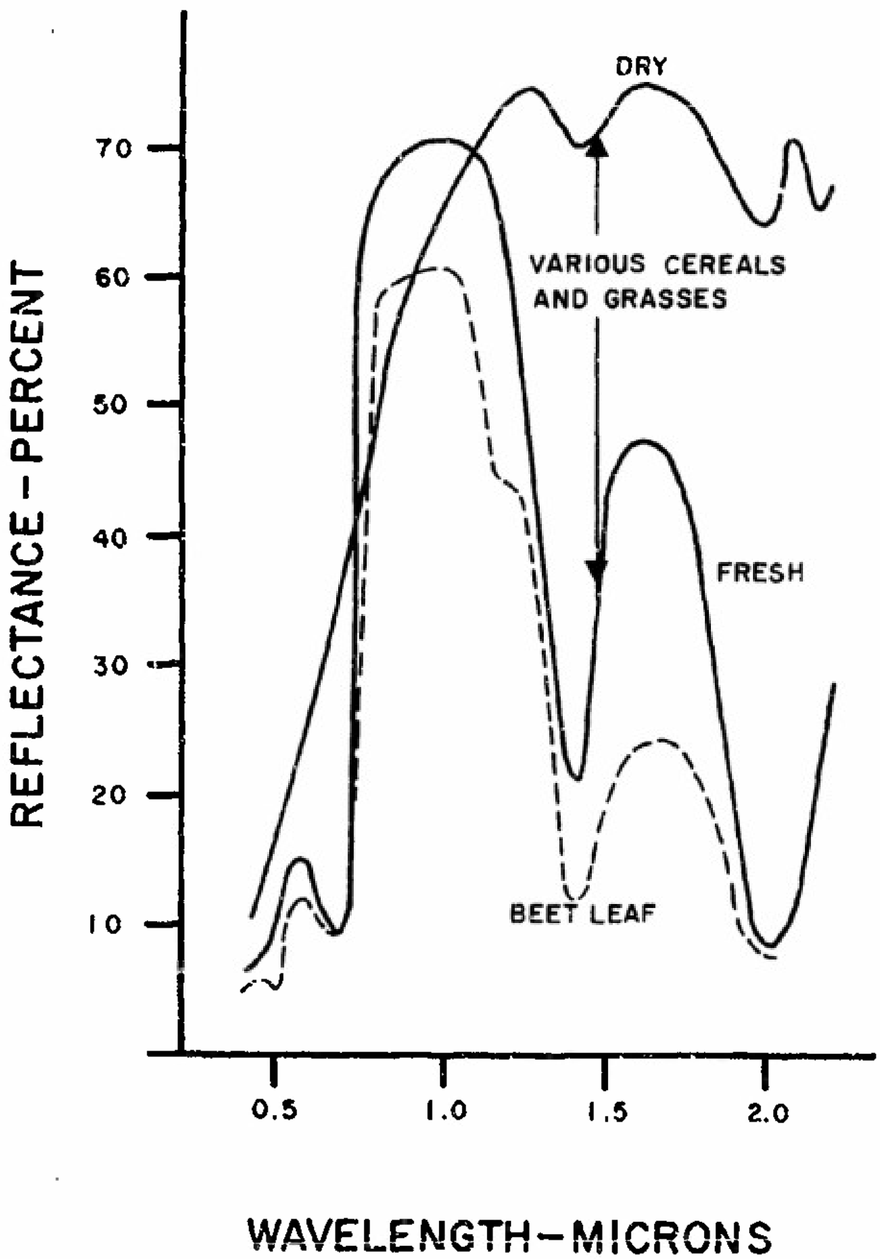

Figure 4. Spectral Reflectance of Typical Crops.

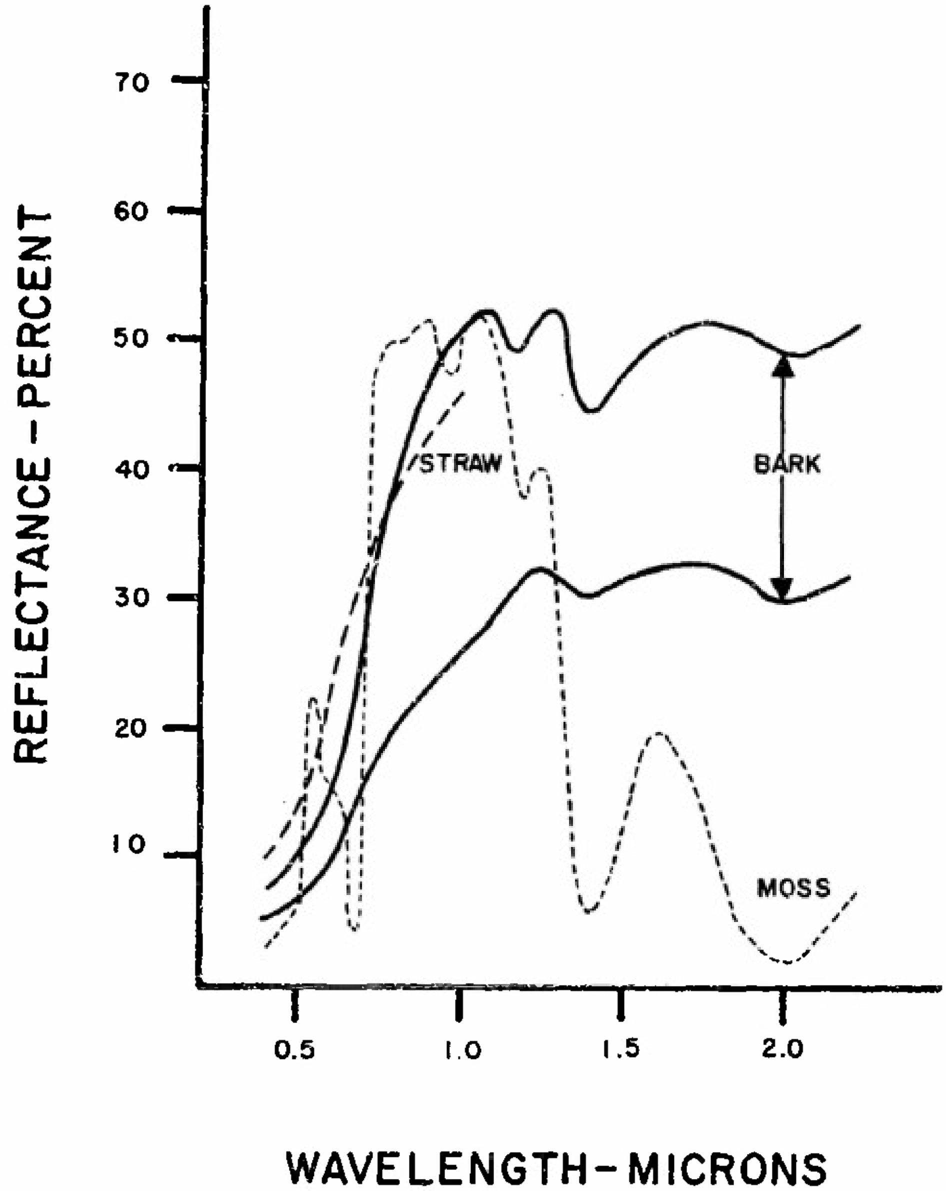

Figure 5. Spectral Reflectance of Typical Examples of Moss, Tree Bark, and Dry Straw.

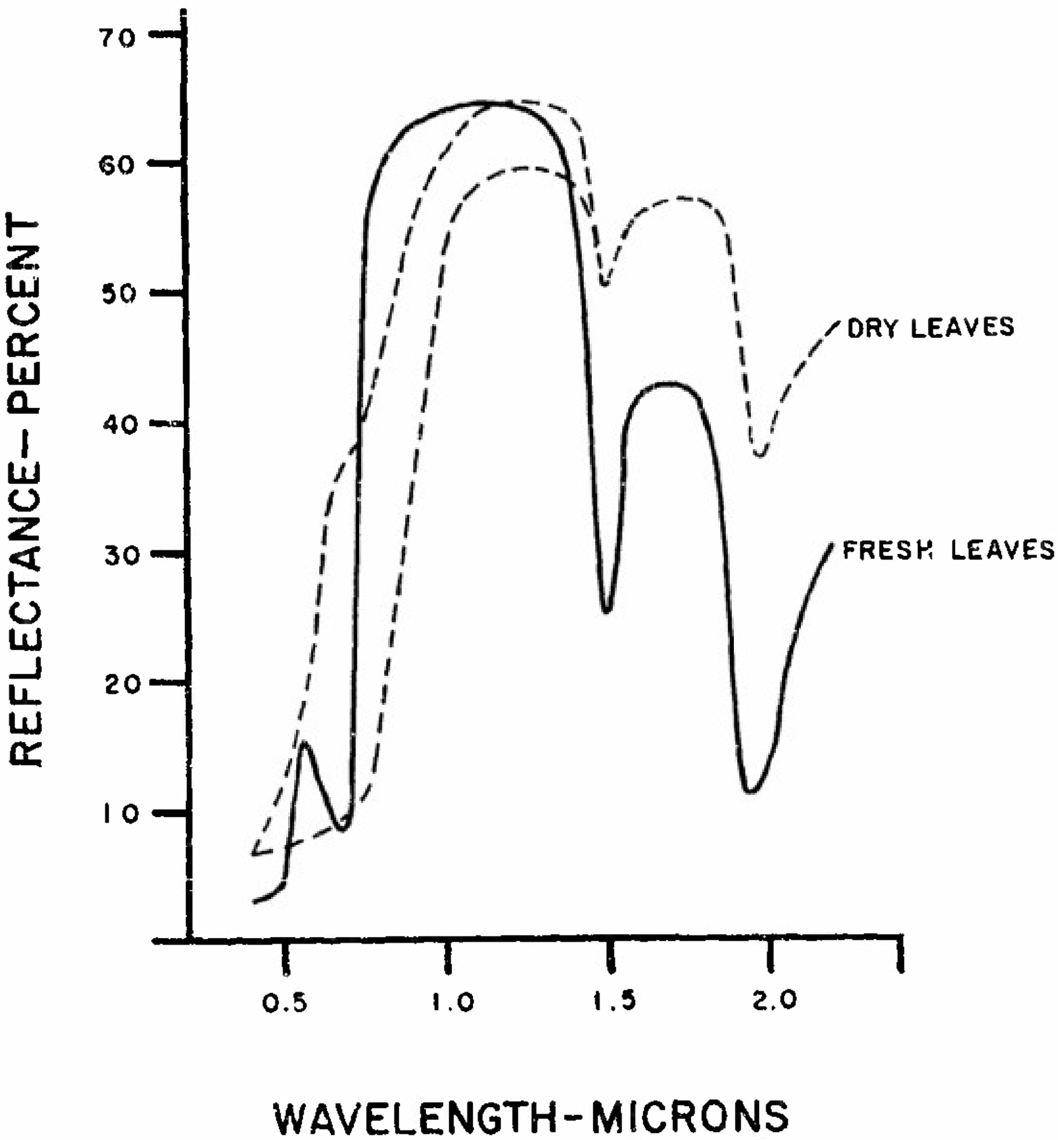

Figure 6. Spectral Reflectance of Typical Leaves of Deciduous Trees.

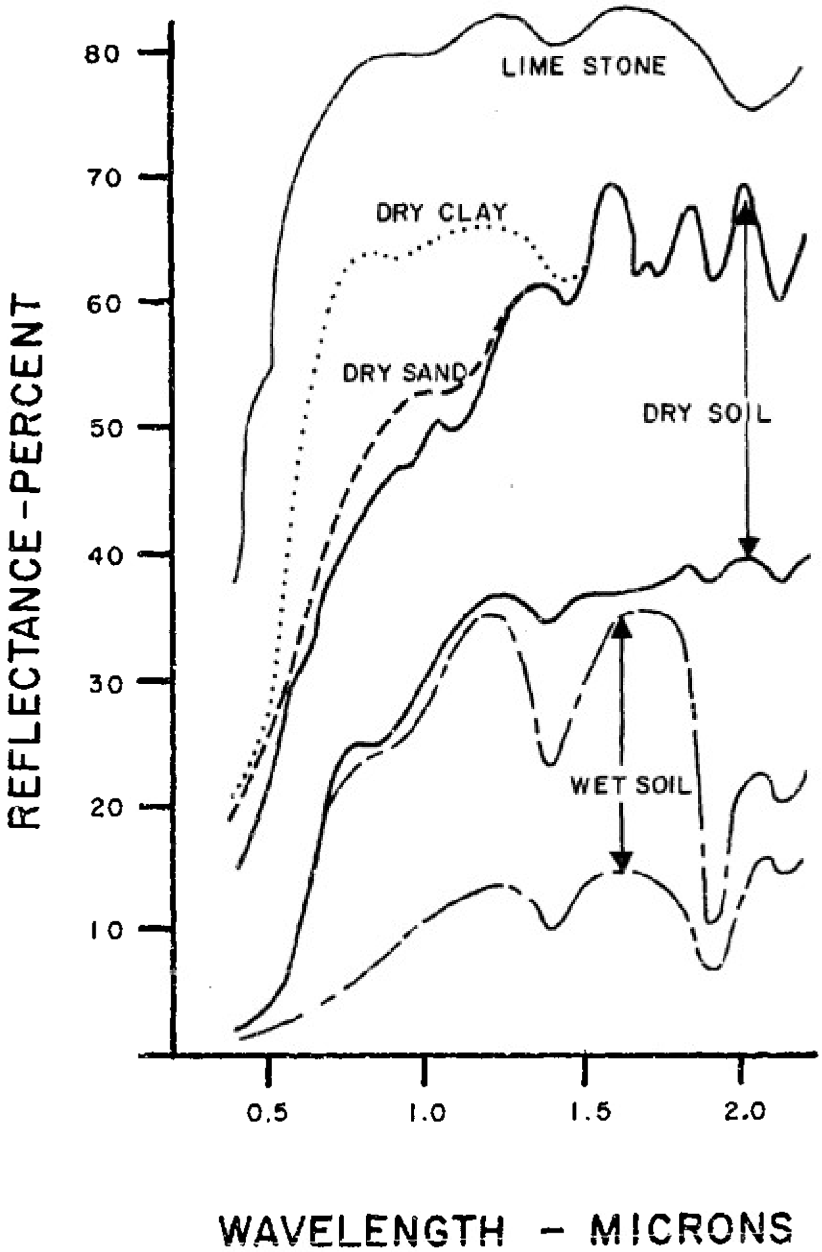

Figure 7. Spectral Reflectance of Typical Bare Soils.

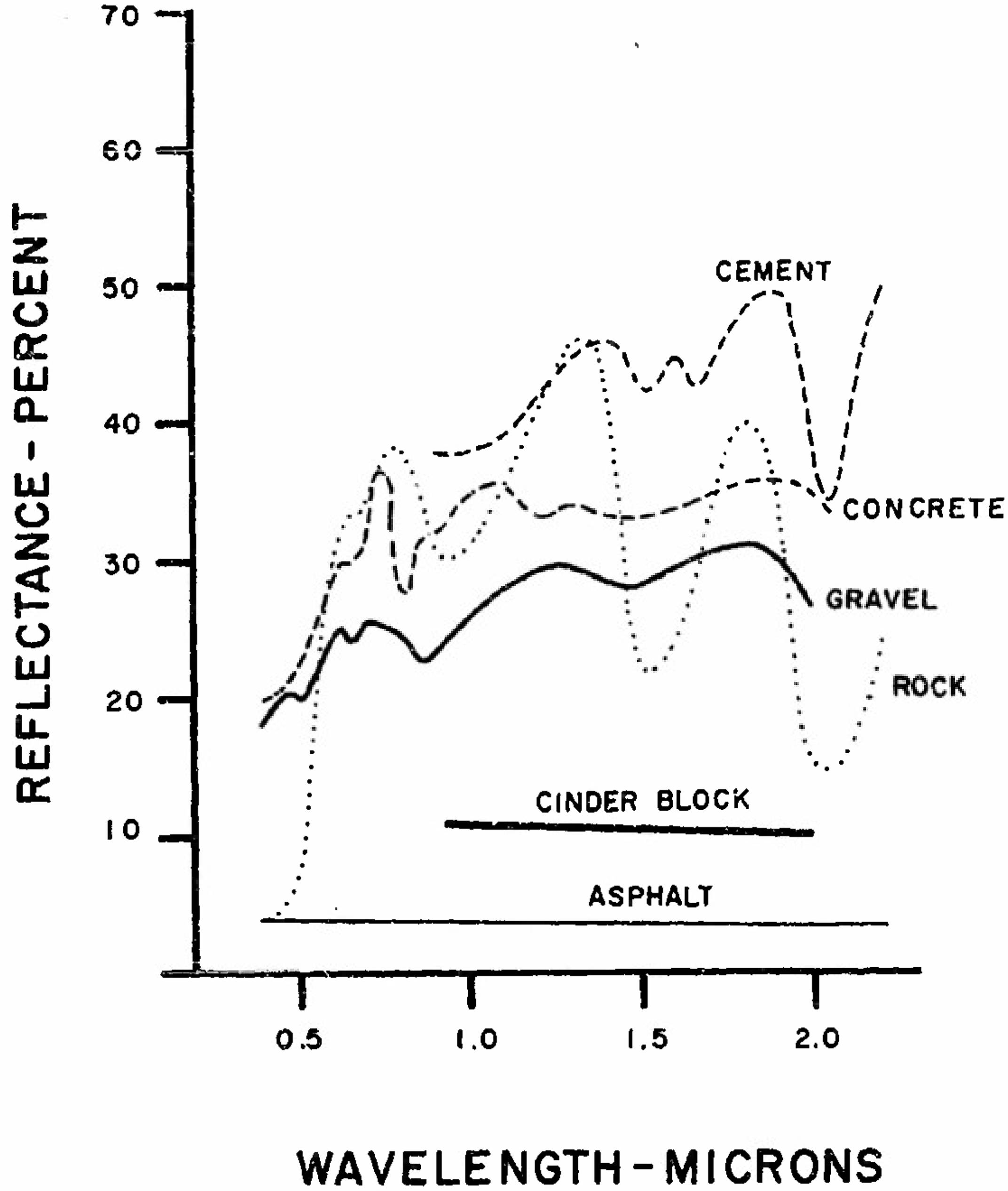

Figure 8. Spectral Reflectance of Certain Building and Road Materials.

the rationale behind the establishment of the reflectance requirements for ideal camouflage against detection by the sniperscope can serve as a guide in the establishment of requirements with respect to the image intensifier.

Figure 9 illustrates the relationship between the source of illumination, target, background, and detector obtained in the use of the sniperscope. Consider that a target T is located 100 yards from a sniperscope and 25 yards in front of a background having a reflectance of 50 percent. What should be the reflectance of the target in order that its image in the sniperscope is exactly the same brightness as that of the background? The brightness of target B_t and background B_b may be expressed as:

$$B_t = \frac{k_1 R_t}{(L_1)^2} \qquad \text{and } B_b = \frac{K_1 R_b}{(L_1+L_2)^2} \tag{4}$$

where k is determined by the output of the sources and scattering of the atmosphere and is approximately the same for both target and background; R_t and R_b are reflectances of the target and background, respectively.

$$R_t = \frac{R_b(L_1)^2}{(L_1+L_2)^2} \tag{5}$$

When these quantities are appropriately substituted with the values assumed above, R_t = 32 percent.

Another contributing feature of the background as it is viewed is the presence of "holes", shadows and voids. Since these have the equivalent of very low (almost zero) reflectance, to minimize contrast with the background, a uniform should have an even lower reflectance than that calculated above.

By a similar analysis, it should be possible to estimate the reflectance necessary to afford optimum camouflage against the image intensifier. Because the source of energy is the diffuse illumination of the whole sky, the brightness of both the background and target is determined principally by their respective reflectances. If the background were uniform, one would expect that the reflectance of ideal camouflage would be the same as that of the background. However, for a horizontal line-of-sight one should expect to find that part of the background consists of tree trunks, rocks, open soil, and shaded areas under trees. It is reasonable to estimate that the reflectance of ideal camouflage against the image intensifier should be somewhat lower than the 60 to 80 percent exhibited by vegetation, but above the level established for camouflage against the sniperscope. Carefully conducted field studies will be necessary to narrow this range to one with reasonable limits, such as ± 5 percent.

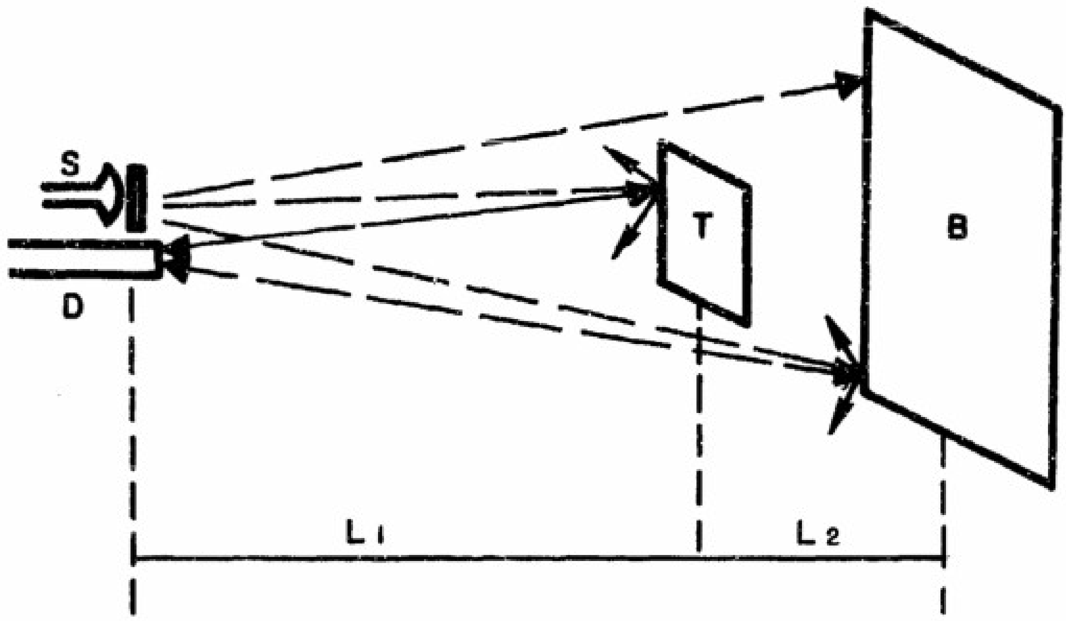

Figure 9. Geometric Arrangement of Target and Background in Relation to a Sniperscope.

5. Acknowledgments

The writer wishes to express his thanks to Dr. Edward M. Healy for his helpful comments in preparation of the manuscript and to Mr. John T. Walwood for making some of the spectrophotometric reflectance measurements.

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
US Army Natick Laboratories
Natick, Massachusetts 01760

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
CAMOUFLAGE OF THE INDIVIDUAL SOLDIER AT NIGHT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
15 July 1967 to 30 January 1968 - **Summary Report**

5. AUTHOR(S) (First name, middle initial, last name)
Alvin O. Ramsley

6. REPORT DATE
March 1968

7a. TOTAL NO. OF PAGES
20

7b. NO. OF REFS
22

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.
1T0-24401-A329

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
68-37-CM

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
C&OM-41

10. DISTRIBUTION STATEMENT
Each transmittal of this document outside the Department of Defense must have prior approval of the Director, Clothing & Organic Materials Laboratory, US Army Natick Laboratories, Natick, Mass. 01760

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
US Army Natick Laboratories
Natick, Massachusetts 01760

13. ABSTRACT

Until the appearance of the sniperscope, a soldier in the field was severely restricted in nighttime surveillance. Since that time, other devices known as image intensifiers have appeared. Although similar in some respects, use of the image intensifier differs from that of the sniperscope in certain basic respects, particularly in that it can function with only the illumination of the night sky.

The object of this study is to determine whether new criteria for personal camouflage exist as the result of the emergence of the image intensifier. Topics considered include: spectral energy distribution of radiation from the night sky, spectral sensitivity functions of typical detectors, reflectance characteristics of the terrain, and the geometric conditions of viewing a scene with the image intensifier. The analysis leads to the conclusion that ideal camouflage against the image intensifier requires reflectance values somewhat higher than those adopted with respect to the sniperscope.

Unclassified

Security Classification

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Camouflage						
Night						
Radiation						
Reflection						
Sky						
Terrain						
Clothing						

Unclassified
Security Classification